Parallel Computations of Turbulent Wakes

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In this study we conducted investigation into the possibility of using a reduced communication scheme in several types of parabolic flows, including laminar, turbulent and transitional regimes. For this purpose an earlier developed LES solver [1-3] was extended with parallel capabilities and applied to several parabolic flow cases on different Beowulf clusters.

The conventional domain decomposition technique for elliptic problems is realized through a two-way exchange of data at the boundaries of the domains [4-5] as illustrated in Fig. 1(a). This guarantees the convergence to the corresponding single domain case. However, this strategy may carry an excessive communication overhead for three dimensional CFD simulations. If the problem is parabolic in one of the spatial directions one can employ a parabolic communication approach (Fig. 1(b)). This may reduce communication overhead by half. To test the validity of this approach a parallel version of the LES code has been implemented using a one-way data exchange [6].

The drawback of the parabolic exchange scheme is the necessity to provide additional outlet boundary conditions for each domain, which can alter the character of the flow close to the domain outlet. To avoid this distortion the communication plane should be set at some distance from the outlet plane. This leads to some loss of the memory space and the processing time. Since the LES solver is usually at least second order accurate, we employed four-node overlaps in our communication schemes. This decomposition scheme was tested on a Beowulf cluster at Pittsburgh supercomputer center (www.psc.edu).

Several test simulations were performed. The communicated data were velocity components and the pressure. In the first case a flat plate wake flow was used. The geometry and numerical scheme were described in [1]. The streamwise velocity contours of both parabolic and elliptic schemes are shown in Fig. 2. As can be seen these flows are rather unsteady, and there is a difference in instantaneous velocity profiles. This difference can always be expected for unsteady flows due to the small variations in inlet/outlet conditions (the "butterfly effect"). In this case this difference takes place because of the difference in communication schemes. Nevertheless, the continuity of the solution across the domain boundaries is present in both cases.

We also performed several steady state simulations. All the results for these cases agree well with those obtained with the 2-way communication scheme. First a laminar channel flow case was computed on 2, 4 and 8 processors. Figure 3 shows the axial velocity contours obtained from the 8-processor run. Although pressure communication was blocked in this simulation the contour lines show almost no irregularities at the inter-processor boundaries. This result indicates the correctness of the decomposition scheme, and supports our assumption that pressure coupling is rather week between the processors. For the case of a wake flow the effect of pressure will be even smaller, thus justifying the velocity-only decomposition strategy.

Next, two flat-plate wake simulations on 4 and 8 processors were done for the wake flow of Reynolds number $1.2 \cdot 10^6$. In both simulations the total number of grid nodes was equal to $224 \times 18 \times 10$, with $28 \times 18 \times 10$ nodes per processor in 8-processor run and $56 \times 18 \times 10$ nodes

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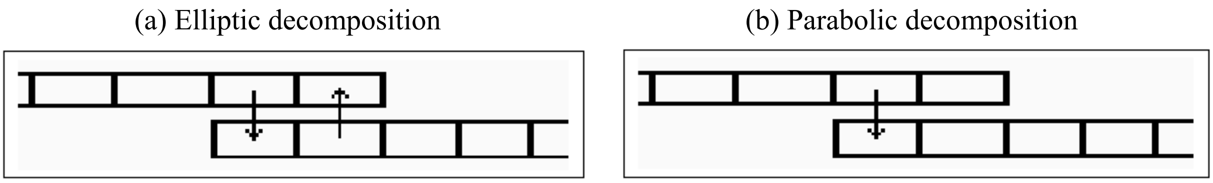
per processor in a 4-processor run. The results were compared so as to look for any possible discrepancy introduced by the communications. Figure 4 shows a good agreement between these two cases on the computed flow-field.

Another simulation of a shear layer flow was performed on 8 processors with the grid size of 250K nodes on each processor. The maximum Reynolds number, based on shear layer thickness was 375. As can be seen in Fig. 5 the development of shear-layer flow-field was not affected by inter-processor communications. The speed of execution of the large-scale run was considerably slower with one iteration computed in approximately 1.5 sec on a DEC-Alpha cluster consisting of 533MHz, 512MB nodes.

The scalability analysis performed for different domain decompositions [7] indicted that the speedup is almost linearly proportional to the number of processors (domains) being used [6].


(a) Elliptic decomposition

(b) Parabolic decomposition

Fig. 1. Domain decomposition strategy.

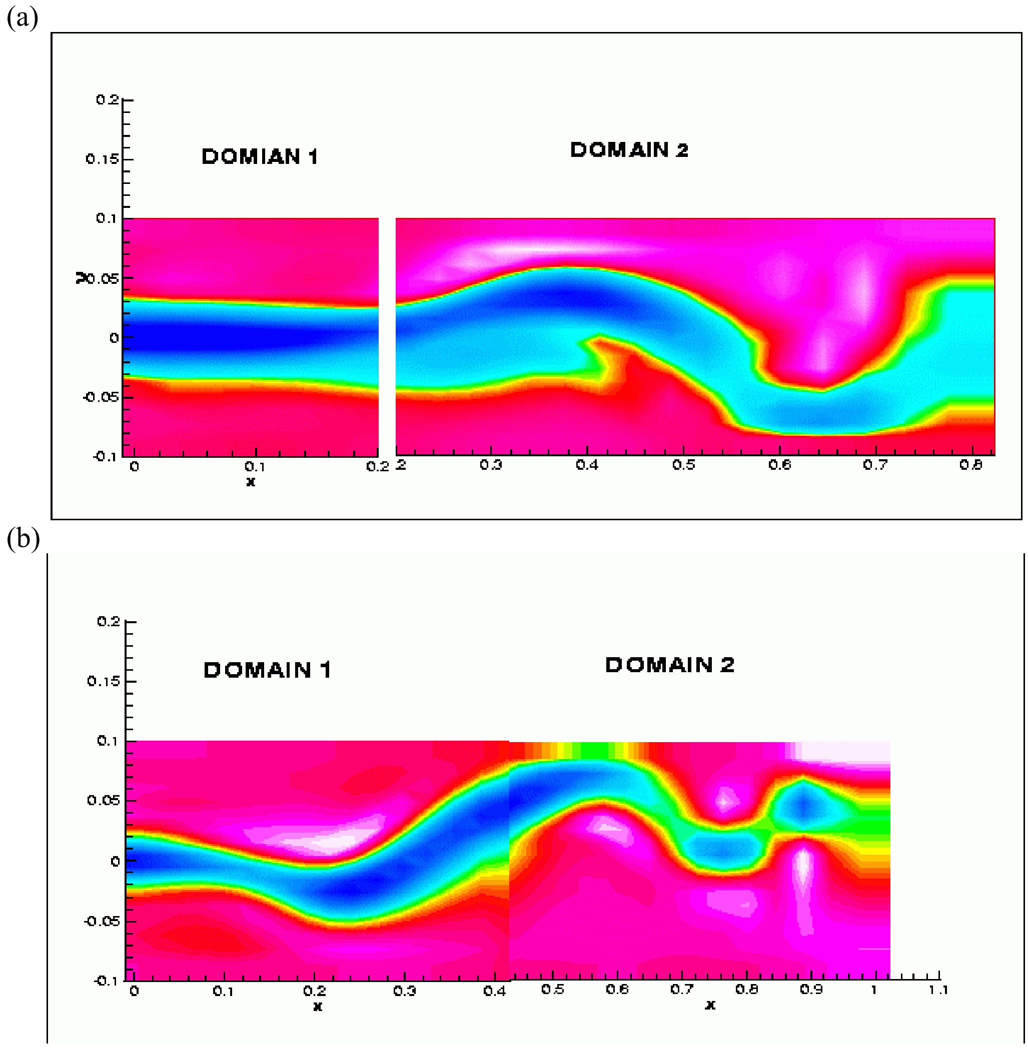


Fig. 2. The streamwise velocity contours for parabolic (a) and elliptic (b) domain decomposition scheme.

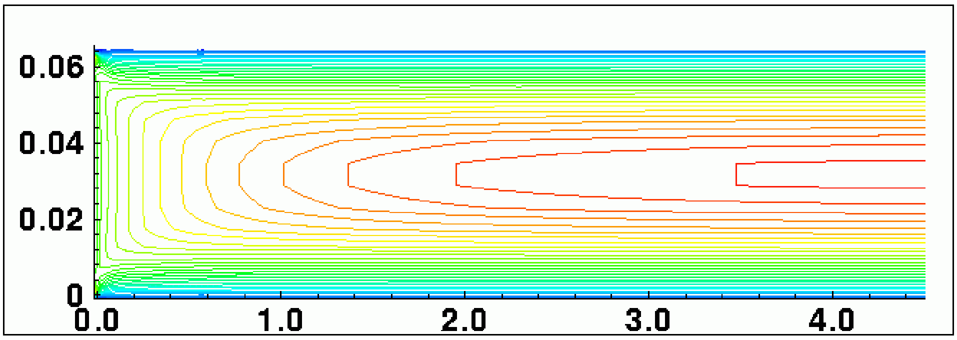
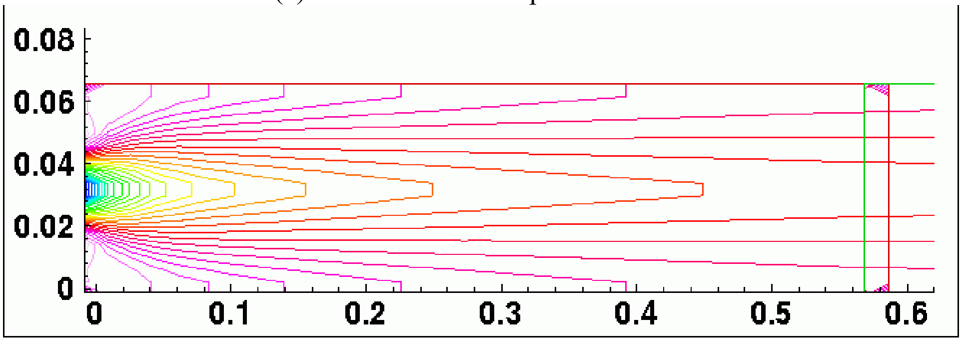


Fig. 3. Laminar channel flow. Results of 8-processor run.
Axes dimensions are given in meters.

(a) 28x18x10-node 4-processor run



(b) 56x18x10-node 8-processor run

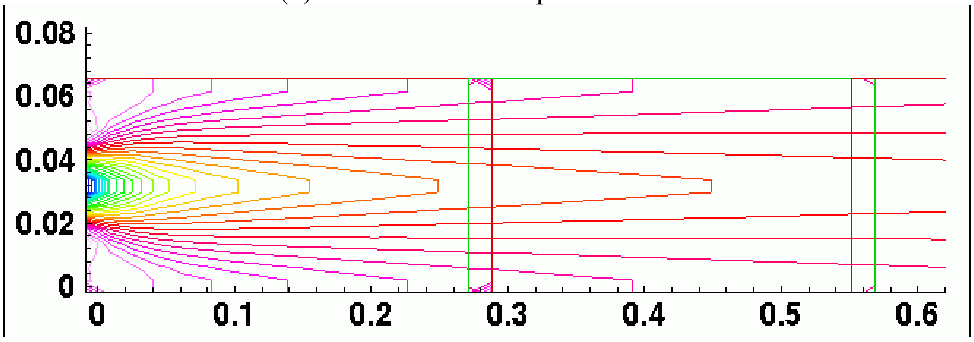


Fig. 4. Comparison of wake simulations on different number of processors.

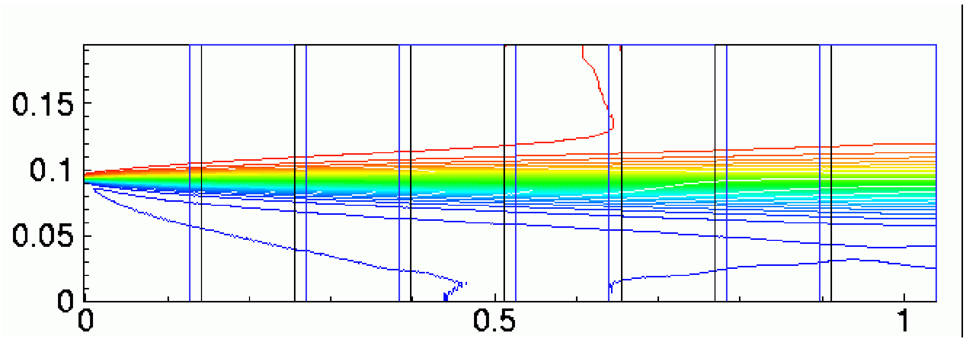


Fig. 5. Large-scale 8-processor simulation (250K nodes on each processor).

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